

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Engineering-geologic maps of northern Alaska,
Harrison Bay Quadrangle

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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INTRODUCTION

Purpose

The purpose of this report is to present information concerning the surficial deposits and bedrock of the onshore part of the Harrison Bay Quadrangle that will be useful in making environmentally sound land management decisions. In addition, this report presents a summary of the depositional history of bedrock and unconsolidated deposits exposed in the Harrison Bay Quadrangle. Information pertinent to land management decisions is presented on maps and in tabular form on sheets 1 and 2, and the list of references following the text will lead the reader to additional sources of information regarding the geologic environment of the Harrison Bay Quadrangle.

General Setting

The Harrison Bay Quadrangle is bounded by latitudes 70° and 71° North and longitudes 150° and 153° West. About 8,020 km², or slightly more than half the total area is land and the remainder is occupied by the Beaufort Sea and its embayments. The principal settlement is the village of Nuiqsut, a town of about 320 people located on the west bank of Nechelik Channel, which is the westernmost distributary of the Colville River delta. Colville Village, a smaller settlement, is on Anachlik Island on the east side of the Colville River delta. Gravel airstrips are present at both settlements and commercial air service is available to Nuiqsut.

The Harrison Bay Quadrangle lies entirely within the Arctic Coastal Plain physiographic province (Wahrhaftig, 1965). Most of the map area is within the Teshekpuk Lake section of the Arctic Coastal Plain, which is a flat to gently rolling tundra-covered surface with numerous thaw lakes. The maximum altitude in the Teshekpuk Lake section is about 60 m and occurs in the southeast part of the quadrangle in an area of large, stabilized dunes. The altitudes of topographic highs gradually decrease northward, and at the coast the maximum altitudes range from 1 to 7 m at the tops of low coastal bluffs.

A portion of the White Hills section of the Arctic Coastal Plain occurs in the southeast corner of the quadrangle, and is the extreme northern part of a broad, northeast-sloping plateau. The edge of the plateau in the Harrison Bay Quadrangle is a degraded, northeast-trending bluff, the base of which is at an altitude of about 60 m. The plateau surface, which contains scattered thaw lakes, reaches a maximum altitude of about 125 m.

The major drainageways within the quadrangle are the Colville and Itkilik Rivers, which head in the Brooks Range. Both rivers flow within a single broad valley which at the south edge of the map is incised 35 to 40 m below the adjacent terrain. The Itkilik River joins the Colville River near the head of the Colville River delta. Streams within the Harrison Bay Quadrangle east of the valley of the Colville and Itkilik Rivers head on the coastal plain; streams west of the Colville River head on the coastal plain or in the Arctic Foothills.

Details of the topography are given under Topography and Drainage in the description of map units for this report. Information about the history of landscape development is incorporated in later sections.

Previous Work

The earliest geologic investigations were carried out by Schrader (1904) during a traverse across the Brooks Range, down the Anaktuvuk and Colville Rivers, and along the arctic coast to Cape Lisburne. Leffingwell (1919) made geologic observations along the Beaufort Sea coast, and summarized the observations of others who travelled the coast between 1826 and 1912. Smith and Mertie (1930) prepared a regional report on the geology of northwestern Alaska.

From 1944 to 1953 the U.S. Geological Survey aided the U.S. Navy in evaluating the resources of what was then called Naval Petroleum Reserve No. 4 (Reed, 1958), which included the part of the Harrison Bay Quadrangle west of the Colville River. Regional reports and maps based on these studies were prepared by Gryc and others (1951), Payne and others (1951), and by Lathram (1965). The geology of a part of the Harrison Bay Quadrangle was described by Brosgé and Whittington (1966). An examination of the unconsolidated deposits of the Petroleum Reserve and adjacent areas was carried out in 1949-50 by Black (1964).

Between the time of Black's fieldwork and the publication of his report, a study of the Quaternary geology of the Arctic Coastal Plain was carried out by O'Sullivan (1961). Interpretations of the late Cenozoic sea level history of the Arctic Coastal Plain are contained in O'Sullivan (1961), Black (1964), McCulloch (1967), Hopkins (1967), Sellmann and Brown (1973), Brigham (1983, 1984), and Carter and Brigham-Grette (in press).

For the past 20 years, research on the Colville River drainage basin and delta has been carried out by H.J. Walker of Louisiana State University and his students and colleagues (Walker, 1983).

With the passage of Public Law 94-258, the National Petroleum Reserve Act of 1976, Naval Petroleum Reserve No. 4 was renamed National Petroleum Reserve-Alaska (NPRA) and was placed under the jurisdiction of the Department of the Interior. An evaluation of the potential environmental impacts of oil and gas development was published by the Department of the Interior in 1979 (U.S. Department of Interior, 1979). The U.S. Geological Survey was assigned responsibility for exploration for oil and gas, and carried out an exploration program during 1976-81 (Bird, 1981a).

This Study

This report presents information obtained by fieldwork during the summers of 1977-1984. Fieldwork during 1977 and 1978 was done in support of Chapters 105b (Environmental Impact Assessment) and 105c (Land Use Study) of the National Petroleum Reserve Act of 1976 (PL 94-258). From 1979 through 1981 fieldwork was carried out as part of the U.S. Geological Survey's Arctic Environmental Studies Program, and in 1984 fieldwork was supported by the Survey's Branch of Oil and Gas Resources. Fieldwork in 1982 and 1983 and the production of this report was done as part of the Northern Alaska Engineering Geology Project, for the purpose of providing engineering/surficial geologic information to the Minerals Management Service and the Bureau of Land Management.

Information on the subsurface geology of the Harrison Bay Quadrangle is contained in a number of reports that detail the Geological Survey's investigations in the National Petroleum Reserve in Alaska (Hittelman, 1982). This report concerns only the rocks and sediments visible in surface exposures, which occur in stream, lake, and coastal bluffs.

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DEPOSITIONAL HISTORY

The Harrison Bay Quadrangle contains sedimentary deposits that range in age from Cretaceous to Holocene and record an interesting geologic history that has been only partly determined. The sediments accumulated in a variety of depositional environments under contrasting climatic regimes, and sediment sources were at various times the Brooks Range, the Canadian Arctic, and an undetermined provenance.

West of the Colville River valley only upper Cenozoic unconsolidated deposits are exposed, except for one locality on the Ublutuoch River where sediments of the Tertiary Sagavanirktok Formation are exposed. In the bluffs on the west side of the Colville River, unconsolidated deposits unconformably overlie the Cretaceous Prince Creek Formation and the Sagavanirktok Formation.

East of the Colville River the Sagavanirktok Formation is exposed beneath unconsolidated deposits in valleys that incise the White Hills section of the Arctic Coastal Plain, and, to the north, in a few cutbanks of the Kachemach and Miluveach Rivers. Elsewhere, only unconsolidated deposits are exposed.

Bedrock

Prince Creek Formation

The oldest deposits exposed in the Harrison Bay quadrangle are nonmarine deltaic beds (Kp) which form part of the type section for the Kogasukruk Tongue of the Prince Creek Formation (Brosigé and Whittington, 1966). These rocks dip less than 5° to the northeast and are exposed in bluffs along the west side of the Colville River from the south margin of the quadrangle north for about 12 km. A fission-track age of 50.9 +/- 7.7 Ma was obtained on a tephra from these beds (Carter and others, 1977). However, this age is now questioned owing to the discovery of Hadrosaurian (duck-billed) dinosaur remains stratigraphically above the tephra (Carter, unpublished data, 1984; Davies, in press), because dinosaurs are unknown from post-Cretaceous deposits. Although, as inferred by Gryc (1951), Late Cretaceous seems the most likely age for these deposits, the tephra is being redated to further evaluate the possibility that the dinosaur remains are Tertiary.

Sagavanirktok Formation

The Sagavanirktok Formation includes three formally named members and was defined to include all Tertiary deposits above the Prince Creek Formation and below the Gubik Formation (Detterman and others, 1975). Deposits of the Harrison Bay quadrangle that we assign to the Sagavanirktok Formation are of marine and nonmarine origin. However, we have not assigned these deposits to the formally defined marine and nonmarine members of the Sagavanirktok Formation because the Harrison Bay deposits differ from the formally defined members in terms of age, fauna, gravel-clast rock types, and environments of deposition. Only the youngest of the Harrison Bay deposits is informally named.

Unnamed Marine Deposits

Nearly flat-lying marine strata conformably or disconformably overlie the deltaic deposits of the Prince Creek Formation, and are well exposed in the Colville River bluffs from their contact with the Prince Creek Formation downstream to the end of continuous bluff exposures near Ocean Point.

The age of the marine beds is controversial. MacBeth and Schmidt (1973) first reported marine deposits near Ocean Point and examined the benthic foraminifers in them. They assigned the beds a Campanian age and referred them to the Schrader Bluff Formation, which intertongues with the Prince Creek Formation in other areas. The foraminifers are now thought to be younger (Carter and others, 1977) but have not been studied in detail. Palynological data have been interpreted to indicate a late Cretaceous age (Frederiksen and others, in press). However, marine mollusk and ostracode faunas have been interpreted to indicate a Paleocene to early Eocene (Thanetian to Ypresian) age (Marincovich and others, 1983; Brouwers and others, 1984; Marincovich and others, in press). Palynological data cited below for younger deposits indicate that the marine strata can be no younger than Paleocene. We tentatively accept a Paleocene age and assign these beds to the Sagavanirktok Formation.

The Ocean Point marine beds are important because they contain a unique fauna that suggests unusual environmental conditions and has implications for Arctic Ocean paleogeography and faunal evolution. The mollusk and ostracode faunas are strongly endemic, with only one species in each group known from faunas elsewhere, which suggests nearly complete isolation of the Arctic Ocean during late Cretaceous and early Tertiary time (Marincovich and others, in press). Further, among the genera with well-known stratigraphic ranges in other regions, some are reported only in Cretaceous and older faunas, some only in Paleogene faunas, and others only in Neogene-Quaternary faunas. New taxa may have evolved in an isolated Arctic Ocean and later migrated to the northern mid-latitudes.

Unnamed Nonmarine Deposits

Nonmarine deposits (Tsg) which we infer to overlie the marine strata are poorly exposed in the Colville River bluffs at several localities north of Ocean Point. Deposits which we correlate with these beds on the basis of gravel-clast rock types and/or similar pollen assemblages are exposed on the Ublutouch River west of Nuiqsut, and on the Miluveach and Kachemach Rivers east of the Colville River. The deposits consist of moderately to poorly consolidated conglomerate, sand, gravelly sand, and pebbly shale with thin coal beds and locally common lignitized logs.

Many gravel clasts are composed of rock types which do not occur in nearby parts of the Brooks Range, including schist, augen gneiss or gneissic granite, granitic rocks, griesen, rhyolite, rhyolite tuff, and andesite. Clasts of these rock types as large as 1.2 m in diameter occur along the base of the bluffs containing the exposures, and some clasts have faceted shapes characteristic of glacially transported stones (Wentworth, 1936). The nearest possible source for some of the rock types is the Romanzof Mountains, which are 200 km to the east. Transportation of the exotic clasts to the Harrison Bay area by icebergs is unlikely because the deposits are nonmarine. Older deposits in the Harrison Bay area are not known to contain clasts of these rock types, so redeposition also seems unlikely as an explanation for the origin of the clasts. Determination of the source and path of transport for these clasts will certainly aid in understanding the early Tertiary paleogeography and paleoclimate of the North Slope.

Fungal spores from the deposits indicate a latest Paleocene-earliest Eocene age (J. Lentin, written communication, 1984), whereas pollen assemblages contain taxa characteristic of the lowest preserved Paleocene assemblages of Siberia and northwest Canada (Frederiksen and others, in press). According to T.A. Ager (written communication, 1985), "The pollen assemblages from the deposit contain a rich assemblage of conifer pollen types, along with several types of broadleaf deciduous tree and shrub pollen. Taxa represented include Taxodiaceae (probably Metasequoia and/or Glyptostrobus), Pinaceae (e.g., Picea, Larix type, Pinus), Podocarpus, Ulmaceae, Betulaceae, Ericales, Sphagnum, and several types of fern spores". And, "Reconstruction of Paleocene vegetation and climate is tenuous because of the uncertain taxonomic affinities of some pollen types, and because of the probable unreliability of applying environmental requirements of modern representatives of taxa identified in fossil assemblages of such antiquity. In broad terms, the fossil pollen and spore assemblage suggests conifer forests with a significant

deciduous broadleaf component. Understory vegetation probably included Alnus shrubs, ferns, and Sphagnum may have been a significant component of the ground cover. Climate was probably temperate and moist".

At the sites sampled for pollen, exotic rock types were generally present but boulders larger than 50 cm in diameter were not observed. Perhaps the largest boulders, which we believe required glacial ice for long-distance transport, were deposited during relatively brief intervals of severe climate. If glaciation proves to have been contemporaneous with the formation of these deposits, then the sediments may have formed during a relative low stand of the sea or during a period of sea level lowering. Considering the evidence of the pollen and fungal spores, likely times for deposition would have been either the middle Paleocene or early Eocene low stands of sea level and interregional unconformities recognized by Vail and others (1984).

Kuparuk Gravel

The next youngest deposit is pebble, cobble, and boulder gravel (Tg) which has been informally referred to as the Kuparuk gravel (Carter, 1983d). This resistant unit forms bluffs on the upper slopes of valleys cut into the plateau that is part of the White Hills section of the Arctic Coastal Plain.

The age of the Kuparuk gravel is poorly known. It overlies the Paleogene deposits described above and is truncated by a bluff which we infer was formed by coastal erosion during one of the two oldest marine transgressions recorded by deposits of the Gubik Formation. These transgressions occurred during Pliocene time, most likely between 2.4 and 3.5 Ma (Carter and Brigham-Grette, in press and this report). Also, the Kuparuk gravel is older than fluvial terraces which are associated with erratics of the late Tertiary Gunsight Mountain glacial interval described by Hamilton (1979).

Exposures of the Kuparuk gravel are poor and few sedimentary structures have been observed. At one locality, clasts are supported within a clayey sand to silty sand matrix and no clast imbrication is discernable. The deposit at this site is best described as a diamicton. Gravel clasts are composed of resistant rock types common in the nearest parts of the Brooks Range including chert, quartz, quartzite, chert-pebble conglomerate, and siliceous sandstone. Clast size varies widely from place to place, and at some localities clasts as large as 1.5 m in diameter are common. The largest boulder observed was 10 m in diameter. Although no striated surfaces have been observed on these clasts, they are certainly glacial erratics and demonstrate that a Tertiary ice advance from the Brooks Range reached much farther north than previously supposed.

Unconsolidated Deposits

Unconsolidated deposits of marine, fluvial, eolian, colluvial, and lacustrine origin mantle bedrock in the Harrison Bay Quadrangle. The unconsolidated deposits exposed in the bluffs that form the west bank of the Colville River in the Harrison Bay Quadrangle are part of the type section of the Gubik Formation (Gryc and others, 1951). The Gubik Formation was defined by Gryc and others (1951) as including the unconsolidated deposits of the Arctic Coastal Plain that are of Pleistocene age, but Black (1964) broadened the definition to include Holocene deposits, and marine deposits that form part of

the type section are now known to be Pliocene (Repenning, 1983). Glaciomarine deposits which were previously referred to as the Flaxman Formation (Leffingwell, 1919) recently have been reduced to member status within the Gubik Formation (Dinter, in press). Thus the Gubik Formation presently includes all unconsolidated deposits of Pliocene and Quaternary age on the Arctic Coastal Plain.

Marine Deposits

Deposits of at least six late Cenozoic marine transgressions occur within the Harrison Bay Quadrangle (table 1). We correlate one of these with the Pelukian transgression (Hopkins, 1967). The other transgressions, which cannot be securely correlated with transgressions defined by Hopkins, were recently named (oldest to youngest) the Colvillian, Bigbendian, Fishcreekian, Wainwrightian, and Simpsonian transgressions by Carter and Brigham-Grette (in press). Deposits of the three oldest transgressions are probably Pliocene and can be differentiated and correlated across the coastal plain by comparing the extent of epimerization of isoleucine (Ile) to alloisoleucine (Aile) in fossil mollusks (table 1). Deposits of the Pelukian and Simpsonian transgressions are late Pleistocene and have been dated by thermoluminescence (TL). Deposits formed between the Pelukian and Fishcreekian transgression and dated by TL as older than 158 ka are questionably correlated with the middle Pleistocene Wainwrightian transgression.

Between the Colville and Kuparuk Rivers, late Cenozoic marine fossils have not been found south of the highly degraded bluff that truncates the Kuparuk gravel. The break in slope at the base of this bluff occurs at an altitude of about 60 m and is inferred to mark the maximum altitude reached by late Cenozoic marine transgressions on this part of the coastal plain. Present data indicate that this limit relates to either the Colvillian or Bigbendian transgression, but are inconclusive as to which of these transgressions reached the highest altitude.

Colvillian

Deposits of the Colvillian and Bigbendian transgressions generally form the basal 2 to 5 m of map unit QTas, which coincides with the landform referred to as Terrace I by Carter and Galloway (1982). Except for one locality on the Miluveach River where the deposits of these two transgressions are superposed and separated by an unconformity, differentiation of the deposits generally requires determination of Aile/Ile values for fossil mollusks. Values of Hiatella arctica from Colvillian deposits yield Aile/Ile values of .236 +/- .022, whereas those from Bigbendian deposits give Aile/Ile values of .136 +/- .014.

Colvillian deposits extend to altitudes of at least 40 m and are well exposed in bluffs along the Colville River from the south edge of the Harrison Bay Quadrangle north for about 10 km. They unconformably overlie Cretaceous or lower Tertiary strata throughout the extent of the exposures, and they generally are overlain by unconsolidated fluvial deposits. However, at one

<u>Transgression</u>	<u>Maximum Elevation Reached (m)</u>	<u>Age</u>	<u>AlIe/Ile¹</u>		<u>Tentative Correlation with Hopkins (1967)</u>
			<u>Colville River/ Fish Creek Area</u>	<u>Chukchi Sea Coast Area²</u>	
Simpsonian	7	70 Ka to 80 Ka	-----	-----	-----
Pelukian	10	120 Ka to 130 Ka	-----	.014 ± .002	Pelukian
Wainwrightian?	20	> 158 Ka	-----	.038 ± .007	-----
Fishcreekian	25	1.87 Ma 2.48 Ma	.086 ± .004 (6) ³	.090 ± .018	----- ∞
Bigbendian	> 35, < 60	> 2.48 Ma	.136 ± .014 (12) ³	.150 ± .025	Anvilian
Colvillian	> 40, < 60	< 3.5 Ma	.236 ± .022 (8) ³	.235 ± .017	Beringian

¹ Ratios for the total fraction for Hiatella artica.

² From Brigham, 1985.

³ Number of analyses.

Table 1. Marine transgressions of the Harrison Bay Quadrangle

locality they are overlain by 1 to 1.5 m of Bigbendian deposits. Along this part of the bluffs, a femur of the North Atlantic harp seal (Pagophilus groenlandica) was found as float (Repenning, 1983), and could have been derived from either Colvillian or Bigbendian deposits. When Repenning's paper was written, the presence of marine deposits of two ages in the Colville River bluffs had not been established by amino acid geochemistry and it was assumed that the harp seal was from beds correlative with the Bigbendian II deposits near Ocean Point.

Cobbles and boulders locally occur at the base of Colvillian deposits. Rock types present include those characteristic of the Kuparuk gravel (Tg) and those which occur in the Paleogene conglomerate (Tsg). The simplest explanation for the occurrence of these clasts at the base of the Colvillian deposits is that they were incorporated by erosion of the Kuparuk gravel and Paleogene conglomerate during the Colvillian transgression. Some boulders derived from the Paleogene conglomerate occur 15 to 20 km southwest of the nearest outcrop of these deposits, perhaps indicating that the boulders were transported shoreward by sea ice.

Mollusks from deposits of the Colvillian transgression form a diverse assemblage that includes the extinct whelk Neptunia Lyrata leffingwelli (L. Marincovich, Jr., written communication, 1984). The fauna includes taxa of Pacific origin and thus post-dates the opening of Bering Strait, which occurred between 3 and 3.5 m.y. ago (Hopkins, 1972; Gladenkov, 1981). The Colvillian transgression may correlate with Hopkins' (1967) Beringian transgression as defined for the type locality at Nome.

Bigbendian

Deposits of the Bigbendian transgression are best exposed in bluffs along the Colville River from near Ocean Point upstream for about 10 km, where they consist of a basal, transgressive, gravelly beach sand about 1 m thick overlain by about 4 m of well-bedded sandy silt. The basal bed contains cobbles and boulders like those described for Colvillian deposits. The maximum altitude at which Bigbendian deposits have been identified is about 35 m.

Pollen spectra from Bigbendian beds indicate that nearby vegetation was probably coniferous forest dominated by spruce and with significant amounts of tree birch and minor pine and fir, somewhat similar to the modern Anchorage area (Nelson, 1981; Nelson and Carter, in press). If this analogy is correct then permafrost was at most discontinuous and limited to north-facing slopes. A relatively mild climate is also suggested by the presence of sea otter (Enhydra?) remains (Repenning, 1983 and written communication, 1985) and by the mollusk fauna, which is richer than the Colvillian fauna and includes the gastropod Littorina squalida (J. Rosewater, written communication to L. Marincovich, Jr., 1984) and the bivalve Clinocardium californiense (Deshayes) (L. Marincovich, Jr., personal communication, 1985). The modern northern limit of both mollusk taxa is Bering Strait. Modern sea otters cannot tolerate severe sea ice conditions (Schneider and Faro, 1975), and the presence of sea otter remains suggests that the Beaufort Sea was at best seasonally frozen during the Bigbendian transgression.

Carter and Galloway (1982) proposed that the Bigbendian deposits correlate with Hopkins' (1967) Anvilian transgression, but Repenning (1983) referred them to Hopkins' second Beringian transgression. Both suggestions may be correct inasmuch as D.M. Hopkins (written communication, 1985) now believes that the marine deposits on St. George Island which he proposed formed during a second Beringian transgression may instead represent the Anvilian transgression. The marine deposits on St. George Island have a minimum age of 2.19 Ma (Hopkins, 1967, fig. 3). Repenning (1983) indicated a possible age of between 1.7 and 2.6 Ma for the marine deposits near Ocean Point based on the stage of evolution exhibited by the fossil sea otter remains. However, he favored an age of between 1.7 and 2.2 Ma because he considered the period 2.2 to 2.6 Ma to be an unlikely time for the transgression based on Shackelton and Opdyke's (1977) conclusion that the first major accumulation of continental ice in the northern hemisphere occurred between about 2.2 and 2.4 Ma. We think it more probable that the Bigbendian transgression preceded this climatic deterioration and occurred between 2.4 and 2.6 Ma.

Fishcreekian

The Fishcreekian transgression is named for fossiliferous deposits exposed along the north side of Fish Creek (Carter and others, 1979) where cut banks expose marine beds beneath the eolian sand of map unit Qe. Hiattella arctica from these sediments yield Aile/Ile values of $.086 \pm .004$ (table 1). Other deposits that may be equivalent to the marine beds underlie the fluvial deposits of map unit Qam and occur beneath the eolian deposits of the southern part of map unit Qem.

The Fish Creek locality is particularly important because sedimentary structures and fossil mollusks at this site define the position of relative sea level during a part of this high sea-level event, and several mollusk taxa allow conclusions to be drawn about the paleoenvironment. Further, measurements of magnetic polarity, and marine vertebrate and invertebrate fossils provide constraints on the interpretation of the age of the transgression.

From the base upwards, the deposits at this locality consist of 3 to 4 m of distinctly to indistinctly bedded dark-gray silt (unit 1) containing scattered granules of chert and quartz, sparse sand interbeds and sand-filled burrows, scattered mollusk fragments, and a few thin woody stems. Overlying the silt is 5 to 9 m of fossiliferous, brown to gray sand, pebbly sand, and silt (unit 2) that is predominantly trough cross-bedded but includes evenly bedded zones which are relatively thin and discontinuous. Detrital wood and comminuted organic debris are common. Above this is 6 to 7.5 m of poorly exposed, brown, locally cross-bedded sand to pebbly sand (unit 3) that contains scattered shell fragments. Capping the bluff is 8 m of eolian sand (unit 4). Units 3 and 4 are nonmarine deposits which post-date the Fishcreekian transgression.

On the basis of the lithology, stratigraphy, and faunas of the deposits, Carter and others (1979) proposed that units 1 and 2 were part of a bay-or estuary-mouth system which formed while sea level was about 20 or 22 m above present mean sea level. This altitude is coincident with that at the base of a wave-cut scarp 30 km east of Fish Creek and 5 km west of the Colville River delta, and Carter and others (1979) inferred that the Fish Creek deposits and the wave-cut scarp were part of the same coastal system. The scarp truncates

the landform (Terrace I of Carter and Galloway, 1982) beneath which the deposits of the Colvillian and Bigbendian transgressions occur, and correlation of the scarp and the Fish Creek deposits is in agreement with the sequence of marine transgressions indicated by Alle/Ile measurements on marine mollusks, evidence for minimum sea level positions during the two older transgressions, and superpositional relations along the Chukchi Sea coast (Brigham, 1984).

We continue to support these conclusions but have refined our interpretation of depositional environments. Unit 2 was initially interpreted as a beach deposit, but further studies of the sedimentary structures indicate that the deposits formed in a tidal channel. A strong dominant current is indicated by sets of large-scale cross-strata as thick as 4 m, which have consistent fore-set dips to the north-northeast. A nearly opposed subordinant current is indicated by ripple stratification which climbs up the dip of the fore-set beds, and by sets of medium scale cross-strata which have fore-set dips nearly opposed to those of the large scale sets. Detrital organic debris and silt occur as laminae and thin strata which separate sand beds of the fore-sets, and are interpreted as slack water deposits formed at high tide. The north-northeast-setting dominant current suggests that ebb flow was responsible for most sedimentary structures at this locality. Inasmuch as the Beaufort Sea is microtidal now and probably was when these deposits formed, the bedforms preserved were probably continuously subaqueous during their formation. The ostracode fauna reported in Carter and others (1979), which includes both marine and nonmarine ostracodes, supports the interpretation of unit 2 as forming in a tidal channel.

Ostracodes reported from unit 1 by Carter and others (1979) indicate a nearshore marine or marginal marine environment as would be expected for fine-grained, possibly estuarine sediments associated with tidal channel deposits. More recent collections by E.M. Brouwers (written communication, 1984) contain the fresh water ostracode Cytherissa lacustris (Sars, 1863), which we feel supports this interpretation, but also includes an undescribed and extinct species of Pterygocythereis, a genus which today is not commonly found in the environments inhabited by the other taxa reported from this unit. Rather, modern Pterygocythereis species are confined to the Atlantic Ocean and are most common in middle to outer shelf water depths (E. Brouwers, written communication, 1985). In spite of the presence of Pterygocythereis, we interpret unit 1 as having formed by rapid sedimentation in a nearshore, shallow water environment on the basis of the other ostracode taxa, and for the following additional reasons: (1) the presence of several species of benthic foraminifers (Elphidium excavatum alba Feyling-Hansen, Elphidium frigidum Cushman, and Elphidium orbicularis Brady), all of which tolerate relatively low salinities and are most common at water depths of less than 10 m, and one of which (Elphidium orbicularis) is common off river mouths (K. A. McDougall, personal communication, 1985), (2) an absence of dinoflagellates (T.A. Ager, personal communication, 1985), (3) the paucity of ostracodes (8 valves and 2 fragments from 10 samples) (E. Brouwers, written communication, 1979 and 1984), (4) the absence of whole valves of marine mollusks, (5) the abundance of plant debris, including woody stems, (6) the presence of coarse laminae (sand and granules) that contain woody plant debris and comminuted, thin, very fragile shell fragments (fresh water?), and (7) the presence of freshwater algal types, which in one sample represent about 10% of the pollen and spore sum (T.A. Ager, personal communication, 1985).

Marine mammal remains and several mollusk taxa provide information about the marine environment during the Fishcreekian transgression. In 1978 a femur of Enhydra? was collected by us, and later collections contained a molar of Enhydra? (C.R. Repenning, written communication, 1985). The occurrence of sea otter suggests that during the Fishcreekian transgression the Arctic Ocean was ice-free or only seasonally frozen as it was during the Bigbendian transgression. A warmer sea than today is also indicated by the presence of the bivalve Clinocardium californiense, whose modern northern limit is Norton Sound, and the gastropods Aforia circinata, and Littorina squalida which presently range no farther north than Bering Sea (L. Marinovich, Jr., written communication, 1984).

Pollen assemblages from units 1 and 2 and detrital wood from unit 2 provide evidence for terrestrial conditions during deposition of these beds. Pollen assemblages were analyzed by T.A. Ager (written communication, 1985). Some samples from both units were uninterpretable due to an absence of pollen or extensive reworking of older pollen. Thus it is not possible to reconstruct vegetation conditions for some of the interval represented by the deposits. However, those samples from unit 2 which contained interpretable assemblages are dominated by pollen of herbaceous taxa (sedges, grasses, and composites), but contain pollen of Betula (probably dwarf birch), and Ericaceae (e.g. blueberries), and small amounts of Alnus (alder), Picea (spruce), and Pinus (pine). The last three are interpreted to be present as a result of long-distance transport and/or reworking. Small amounts of Larix (larch) pollen are also present, and wood from this unit has been identified as Larix (D.J. Christensen, written communication, 1985), indicating that larch was present nearby. Accordingly, we interpret the vegetation to have been shrub-herb tundra with scattered larch trees or a larch taiga similar to the modern vegetation of parts of northeastern Siberia.

Those samples from unit 1 which contain interpretable pollen assemblages have assemblages similar to those of unit 2, except for higher amounts of Betula pollen and generally higher amounts of Picea and Pinus pollen. In two samples, pollen from spruce and pine together make up from 17% to 20% of the total pollen and spores, whereas in samples from unit 2 they compose from 2.5% to 8% of the total. This suggests that either spruce and pine were growing closer to the site during the deposition of unit 1, or that regional wind conditions were different, or both (T.A. Ager, personal communication, 1985).

The difference in pollen assemblages between the two units suggests the possibility that they are of different ages. However, we think it most probable that both units formed during the same transgression, and that during this transgression there were minor changes in climate and vegetation. We draw this conclusion because of paleomagnetic data presented below, and because 3 km upstream on Fish Creek, marine mud exposed at the same altitude as unit 1 contain paired valves of Hiatella arctica (L. Marinovich, written communication, 1979) which yield the same amino acid ratios as those for H. arctica from the tidal channel deposits (unit 2) which overlie unit 1.

The pollen assemblages from the tidal channel deposits (unit 2) are similar to those from the late Pliocene or early Pleistocene Cape Deceit Formation (Gitterman and others, 1982), and suggest a severe terrestrial climate. This is in marked contrast to the conditions indicated for the marine realm. A relatively warm ocean adjacent to a cold land provides conditions favorable

for the build-up of ice sheets (Ruddiman and McIntyre, 1979), and it is possible that the Fishcreekian transgression, even though it occurred during an interglacial interval, was coincident with glaciation in the Brooks Range and in the Canadian Arctic. Hamilton (1981) proposed that a northern moisture source nourished glaciers in the Brooks Range during the Gunsight Mountain glacial interval, and perhaps this ice advance was coincident with or closely related in time to the Fishcreekian transgression. The informally named Tuapaktushak beds exposed along the Chukchi Sea coast (Brigham, 1984) and correlated by amino acid geochemistry with the Fish Creek deposits (Carter and Brigham-Grette, in press) contain dropstones and exhibit deformational structures and striated boulder pavements that D.M. Hopkins (personal communication, 1984) believes could have been produced by stranded icebergs.

Paleomagnetic analyses were made on 20 samples from units 1 and 2 at Fish Creek. Five of the determinations are considered unreliable because of unreasonable declinations. The remaining samples were directionally stable and indicate reversed polarity (V. Pease, written communication, 1985). The fact that both units 1 and 2 possess reversed polarity supports the conclusion that both units formed during the same transgression. Paleomagnetic analyses also were attempted for deposits of the Colvillian and Bigbendian transgressions but polarity could not be determined.

Consideration of the sequence of marine transgressions, the paleomagnetic evidence, the palynological data, and the marine fauna leads to the conclusion that the Fishcreekian transgression occurred between 1.87 and 2.48 Ma. The Fishcreekian transgression is younger than the Bigbendian transgression, which, if Repenning (1983) is correct, occurred no more than 2.6 Ma. Because the Fish Creek deposits have reversed magnetic polarity, they must have formed during the Matuyama Superchron and they can be no older than 2.48 Ma. The pollen data support this conclusion, when considered in the light of data from elsewhere. For example, Zagwijn (1974) has shown that there was a dramatic change in vegetational type in the Netherlands as a result of climatic cooling near the Gauss-Matuyama boundary. At about the same time (2.5 Ma), Shackelton and others (1984) report a brief ice rafting episode in the North Atlantic which was followed by a major glacial event about 2.37 Ma. This sequence of climatic deterioration is similar to that inferred from Pacific Ocean deep sea cores (Shackelton and Opdyke, 1977), the terrestrial record on New Zealand (Stipp and others, 1967), and data from the Gulf of Mexico (Beard and others, 1982). Climatic cooling at this time appears to have been world-wide, and we think it unlikely that tundra or larch taiga vegetation would have been present during an interglacial interval on the Arctic Coastal Plain prior to the start of this cooling event.

The *Enhydra*? molar recovered from the Fish Creek tidal channel deposits exhibits a stage of evolution comparable to the *Enhydra*? from Ocean Point (C.A. Repenning, personal communication, 1985) and therefore is most likely no younger than 1.7 Ma (Repenning, 1983). This conclusion is supported by the mollusk fauna, which has a boreal aspect and is more similar in this respect to the fauna of the Tjornes beds of Iceland than to that of the lower Breidavik beds which overlie them. The lower Breidavik beds contain mollusk faunas of a more arctic aspect and are interbedded with tillites. According to Gladenkov (1981, Table 2) the base of the Breidavik beds occurs just above the Olduvai Chron (referred to by him as the Gilsa event) and the top of the Tjornes deposits is about 2 Ma. Thus both the mollusks and the marine

vertebrate fauna suggest that the Fishcreekian transgression occurred prior to the Olduvai Chron, which began about 1.87 Ma.

We think it most probable that this high sea level event corresponds to one of the O^{18} minima recorded in deep sea cores. In the North Atlantic Ocean, significant O^{18} minima within the Matuyama Superchron and prior to the Olduvai Chron occurred at about 2.15, 2.25, and 2.41 Ma (Shackleton and others, 1984). The oldest of these post-dates the first evidence of climatic cooling and immediately predates the first major glacial episode, and we tentatively correlate the Fishcreekian transgression with this O^{18} minimum.

Wainwrightian?

Glaciomarine deposits similar to the Flaxman Member of the Gubik Formation, which is described below, have been dated by TL as older than 158 ka. These deposits occur beneath eolian sand in the northern part of map unit Qem. They most likely represent a Simpsonian-type transgression that occurred before the Pelukian transgression (Carter, 1983d). However, they may be an offshore facies formed during the Wainwrightian transgression (Carter and Brigham-Grette, in press)

Pelukian

The Pelukian transgression was defined by Hopkins (1967) as occurring during the last interglacial interval and producing shoreline features and deposits a few meters above present sea level that can be traced discontinuously around the coast of western and northern Alaska. Beach deposits of last interglacial age in the Harrison Bay Quadrangle are exposed in bluffs along the north shore of Teshekpuk Lake and can be traced eastward to Harrison Bay and northwestward to near Barrow. These deposits occur at altitudes that range from 1 m at their base to perhaps as much as 10 m at their top. In the Harrison Bay Quadrangle, these deposits occur along the north edge of map unit Qs, where they overlie marine mud and are disconformably overlain by lacustrine or deltaic deposits and by eolian sand. Spruce driftwood is common locally in the deposits and the foraminifera and ostracode faunas indicate more open water and warmer climatic conditions than presently prevail (Hopkins and others, 1981). Amino acid ratios determined for the bivalve Hiatella arctica are barely distinguishable from those determined for modern specimens (Brigham, 1983), and preclude an age greater than the last interglacial episode. Oxygen isotope analyses of the bivalve Astarte borealis show that their O^{18} content is about the same as that of modern A. borealis shells (J.R. O'Neil, written communication, 1984), suggesting a correlation with oxygen isotope stage 5e. This correlation is supported by seven TL dates on the beach deposits and underlying muds that range from 108.5 ka to 140 ka and average 123.5 ka. The altitude of beach deposits formed during the Pelukian transgression is about the same as that estimated for the eustatic high-stand during isotope stage 5e based on evidence from oceanic islands and other continental shelves (Cronin and others, 1981), and suggests that this part of the western Arctic Coastal Plain has been tectonically stable for the past 125,000 years. The Pelukian transgression can be confidently correlated with the informally named Walakpa beds of the Chukchi Sea coast (Brigham, 1983).

Simpsonian

The Simpsonian transgression is defined as the transgression during which the Flaxman Member of the Gubik Formation was deposited. The Flaxman Member occurs locally along the Beaufort Sea coast to altitudes of about 7 m. In the Harrison Bay Quadrangle these deposits form the upper part of map unit Qm. They consist of a few meters of glaciomarine erratic-bearing silt, clayey silt, and silty sand, and they are overlain locally by regressive sand, beach, deltaic, or fluvial deposits. The erratic stones are of Canadian provenance and rock types include dolomite, diabase, pyroxenite, granite, and quartzite (McCarthy, 1958). Erratics occur to within a few hundred meters of the southern limit of the deposit, and so were being supplied at the peak of the transgression (Hopkins, 1982). Their transport to the Beaufort Sea coast by icebergs records the breakup of an ice sheet in the Canadian Arctic. Remains of Pacific marine mammals, including ribbon seal (*Histiophoca fasciata*) and gray whale (*Eschrichtius* sp.) (Repenning, 1983), indicate that a connection with the Bering Sea existed at this time. Mollusk, ostracode, and foraminifera faunas are depauperate and include no extralimital species (Hopkins and others, 1981). The Simpsonian transgression was a brief event of a distinctly different character than the interglacial transgressions discussed above.

Eleven TL dates on sediment of the Flaxman Member range from 53 ka to 81 ka. Six of these are between 71 and 76 ka and a uranium series date on whale bone from Simpsonian deposits is 75 ka (J.L. Bischoff, written communication, 1984). Finite radiocarbon dates previously obtained for organic remains from Simpsonian deposits (Carter, 1983d) are apparently erroneous, and the Simpsonian transgression most probably occurred between 70 ka and 80 ka.

Because the western part of the Arctic Coastal Plain has been tectonically stable for at least the past 125 ka, the altitude of the Simpsonian deposits cannot be attributed to tectonism. Furthermore, marine deposits exposed near sea level on the Atlantic Coastal Plain were deposited about 75 ka (Cronin and others, 1981; Cronin and others, 1984), suggesting that the Simpsonian transgression was not a local event but represents a eustatic sea level higher than that of today. However, marine mollusk shells from Simpsonian deposits are enriched in O^{18} relative to modern specimens from the Beaufort Sea, indicating that more glacial ice was present during the Simpsonian transgression than occurs today. Oxygen isotope data from deep sea cores for this time interval also indicate large volumes of glacial ice.

Cronin and others (1984) proposed that the paradox of high sea level 75 ka co-occurring with extensive glacial ice could be explained by large volumes of floating glacial ice in polar regions. The Flaxman Member does indeed document that floating glacial ice was present in the Arctic Ocean, but the discrepancy between the sea level and isotope records is so large that an extraordinary amount of floating glacial ice would be required to reconcile them. Possible mechanisms to provide an enormous amount of floating glacial ice would be a surge of the East Antarctic ice sheet or disintegration of the West Antarctic ice sheet. Either of these would cause a rapid rise in sea level (Wilson, 1964; Mercer, 1978; Hollin, 1982) and might lead to the catastrophic breakup of unstable marine-based ice over the central Canadian Shield (Denton and Hughes, 1983). Recent studies of amino acid geochemistry

of marine mollusk shells in the Hudson Bay region do indeed indicate that the Hudson Bay Lowlands were evacuated of Laurentide ice and inundated by marine waters about 75 ka (Andrews and others, 1983).

Fluvial and Deltaic Deposits

Fluvial deposits consist of Pliocene gravelly sand (Tgs) which underlies the deposits of map unit QTas east of the Itkillik River, Pliocene and Pleistocene sand and gravelly sand which overlies the marine deposits of map units QTas and Qam, Pleistocene sand and gravelly sand which composes the alluvial terrace deposits of map unit Qat, and Holocene and latest Pleistocene sandy alluvium of map unit Qal.

The oldest deposits (Tgs) are very poorly exposed and they have yielded no fossil plants or animals. The fluvial deposits of map units QTas and Qam form broad alluvial plains which are not related to modern river valleys. Pollen studies show that some of the deposits formed during glacial intervals (Nelson, 1981), and spruce, larch, and poplar macrofossils indicate that other deposits formed during interglacial episodes (Carter and Galloway, 1982; Carter, unpublished data). These deposits contain a rich paleoenvironmental record and detailed sampling of key localities should be carried out.

Fluvial terrace deposits are confined to modern river valleys but probably are stratigraphically complex and formed over a long period of Pleistocene time. The oldest of these deposits underlie ancient flood plains of the Miluveach and Kachemach Rivers which are graded to the base of a scarp that trends perpendicular to the two rivers (Carter and Galloway, 1982). The scarp may be of fluvial or marine origin. If it is of marine origin it probably formed during the Fish Creek transgression.

Younger Pleistocene fluvial terrace deposits occur on both sides of the Colville and Itkillik Rivers. These deposits underlie several terrace surfaces and their ages are undetermined. Fossil spruce logs have been collected at several localities (Carter and Galloway, 1982), suggesting that the deposits formed during interglacial intervals.

Holocene and latest Pleistocene alluvium forms flood plains and low terraces along modern streams of the Harrison Bay quadrangle. These young deposits have not been studied in detail, but radiocarbon dating of correlative deposits in adjacent quadrangles indicate that the terraces formed between 8 ka and 14 ka, which suggests that the streams in the Harrison Bay Quadrangle were not deeply entrenched during late Wisconsin low stands of sea level.

Extensive deltas (Qd) of silt and sand have formed at the mouths of the Colville River and Fish Creek since sea level reached its present position during middle or late Holocene time. The thickness of these deposits has not been determined, but they may not be thicker than 15 m, which is the approximate depth of the thalweg of the main distributary of the Colville River delta. Extensive studies of the geomorphology of the Colville River delta and processes of erosion and deposition there have been carried out by Walker (1983).

Eolian Deposits

Eolian deposits consist of a blanket of silt and very fine sand in the southeastern part of the quadrangle that is referred to here as upland sand and silt (Qus), and of eolian sand that forms stabilized dunes, sand sheets, and fossil sand wedges elsewhere.

The upland sand and silt is very poorly exposed and has been examined only in reconnaissance fashion. It overlies the Kuparuk gravel and forms the surface deposits of the plateau that makes up this part of the White Hills section of the Arctic Coastal Plain. The deposits accumulated over a long period of time and the most recent episode of deposition was most likely during either the late Wisconsin or early Holocene intervals of eolian sediment transport documented for other parts of the coastal plain (Carter, 1983a). The sediments have been reworked in many places by lacustrine, fluvial, and colluvial processes, and form the matrix for the deposits mapped as colluvium within the area of the plateau. These colluvial deposits contain the bones of extinct Pleistocene mammals such as horse and bison.

Eolian sand deposits in the remainder of the quadrangle formed during several intervals of eolian sediment transport which occurred in contrasting climatic regimes during Pleistocene and Holocene time. Stabilized linear dunes as much as 20 km long, 1 km wide, and 30 m high form the major part of the eolian sand of map unit Qe. These large dunes form the northeastern part of a sand sea that covered more than 11,000 km² of the Arctic Coastal Plain (Carter, 1981, 1983a). The time of initiation of the dune field has not been determined, but radiocarbon ages of herbaceous plants from eolian and lacustrine sand within the dune field indicate that the dunes were active from before 36,000 to nearly 12,000 yr B.P. Bedding attitudes, dune-ridge orientations, and measurements of pseudocrosslamination formed by climbing adhesion ripples demonstrate a wind regime similar to that of the present and indicate that the dominant directions of sand-moving winds were easterly to northeasterly. Stratification types within the dunes indicate deposition under predominantly dry conditions. Few interdunal pond deposits have been identified, suggesting that rainfall and snowmelt were insufficient to regularly inundate interdunal depressions. Buried snow or ice has not been observed in the dune sand, and deformational structures that could be attributed to the melting of snow or ice are rare. Snow cover over the dunes is inferred to have been patchy at most.

In spite of this evidence for aridity on the Arctic Coastal Plain, radiocarbon dating of fossil bones indicates that before 28 ka vegetation in the Arctic Foothills was sufficient to support such large herbivores as mammoth, horse, and bison. However, none of the dates on these mammals is less than 28 ka, and few organic remains have been found in deposits between 14,500 and 28,000 years old in contrast to both older and younger deposits. Cold, arid conditions evidently intensified during late Wisconsin time-coincident with the expansion of glaciers in the Brooks Range.

In support of this conclusion, TL dating of fossil sand wedges which are as much as 7 m deep and 3 m wide and extend upwind of the dunes for more than 100 km shows that they formed during late Wisconsin time (Carter, 1983c and unpublished data). Sand wedges are forming today in the drier parts of Victoria Land, Antarctica (Pewé, 1959; Black and Berg, 1963; Berg and Black,

1966), in some parts of the Sverdrup Islands of arctic Canada (Hodgson, 1982), and in northern Greenland (C. Hjort, written communication, 1983). They form in a manner analogous to ice wedges, which commonly underlie the borders of nonsorted polygons in tundra covered arctic areas. Both sand and ice wedges grow as a result of repeated formation and filling of thermal-contraction cracks in permafrost; ice wedges form when the cracks fill with snow, hoar frost or meltwater (Leffingwell, 1915; Lachenbruch, 1962), whereas sand wedges form when the cracks fill with sand that trickles down from the surface. Sand wedges developed on the Arctic Coastal Plain as wind-driven sand moving across the coastal plain toward the dunes dropped into open thermal-contraction cracks. The sand wedges record barren ground and document an absence of surface water from the time the thermal contraction cracks formed in middle and late winter until they filled with eolian sand. This suggests that significant sand movement occurred before spring and that snow cover was patchy or absent as inferred for the dunes.

About 12 ka the dunes were stabilized and the development of organic soils began across the coastal plain (Carter, 1983c). In conjunction with soil development, ice wedge growth was initiated locally on the previously barren plains north and east of the dunes. About 11 ka a new phase of eolian sand movement was initiated that resulted in the formation of a sheet of eolian sand from 1 to 7 m thick that blanketed the dunes and extended beyond them to the north. This sand-sheet forms the upper part of map units Qe and Qem. Climatic conditions during this episode of eolian sand movement were warmer and drier than those of today (Carter and others, 1984). Eolian sand movement ceased about 8 ka when the development of organic soils stabilized the sand surface.

Small parabolic and longitudinal dunes up to 1 km long and a few meters thick developed over the area of the sand sheet during late Holocene time. This episode of eolian sand movement was probably coincident with the neoglacal expansion of glaciers in the Brooks Range. If so, then destabilization of the sand surface was probably initiated by cooler and drier climatic conditions than those of today.

Thaw-Lake Deposits

Thaw lakes began developing about 12 ka following the climatic amelioration that terminated late Wisconsin glaciation (Lewellen, 1972b; Sellmann and others, 1975; Brown and others, 1980; Carter, unpublished data). Since stabilization of the eolian sand sheet about 8 ka, the thaw lake cycle has perhaps been the dominant form of landscape modification away from rivers and streams. The cyclic development, orientation, and origin of thaw lakes has been extensively studied in the Barrow area (Black and Barksdale, 1949; Britton, 1957; Brewer, 1958a; Livingstone and others, 1958; Carson and Hussey, 1960, 1962, 1963; Brown, 1965; Hussey and Michelson, 1966; Carson, 1968; Black, 1969, 1976; Morrissey, 1979). Sellmann and others (1975) subdivided the coastal plain into areas containing thaw lakes of similar size, shape, and development of orientation. Their map unit boundaries approximate the boundaries of the lithologically defined map units for the Harrison Bay Quadrangle.

The thaw-lake cycle begins when ponding occurs at the surface. This can occur as a result of the disruption of insulating vegetation and consequent melting

of ground ice followed by surface subsidence to create a small basin. The pond may deepen and expand laterally by thaw of subjacent and adjacent ice-rich permafrost, and as a result of wind-induced erosion by waves and currents. Wind-induced erosion produces the lake elongation that is so distinctive on the Arctic Coastal Plain (Carson and Hussey, 1962). The prevailing east-northeast and west-southwest winds create waves and currents which build protective shelves on the downwind shores and concentrate erosion on the north-northwest and south-southeast shores. Lake-basin depth is determined by the ice content of the underlying materials and their potential for thaw settlement. Lake expansion may continue until a lower lake basin or stream is intercepted and the lake drains. Following drainage, the lake bed is refrozen to form new ice-rich permafrost and ice wedges begin to grow. During refreezing, pingos (ice-cored conical hills) commonly develop in lake basins which are underlain by thick granular materials (Galloway and Carter, 1978; Carter and Galloway, 1979). After refreezing, a new thaw lake cycle may begin. The parts of the landscape that occur between thaw-lake basins and that either have not been affected by the thaw-lake cycle or have not been affected for several thousand years have a much higher ice content than recently drained lake beds or the beds of existing lakes.

The character of thaw-lake deposits depends upon the character of the materials in which the thaw-lake basin develops. However, as explained in the description of map units, thaw lake deposits generally have a higher organic content than adjacent sediments, owing to the incorporation of eroded tundra vegetation.

Colluvial Deposits

Colluvial deposits are of minor extent in the Harrison Bay Quadrangle. They are poorly exposed and the history of deposition has not been adequately determined. Some of the deposits are relict and contain the remains of extinct Pleistocene mammals. These deposits commonly underlie paired terraces in tributaries to main valleys in the southeast corner of the quadrangle. They contain abundant organic debris and may date to the warm period that occurred from 12 ka to 8 ka (Carter and others, 1984). If so, then the mammal bones were most likely incorporated in the deposits by colluvial processes.

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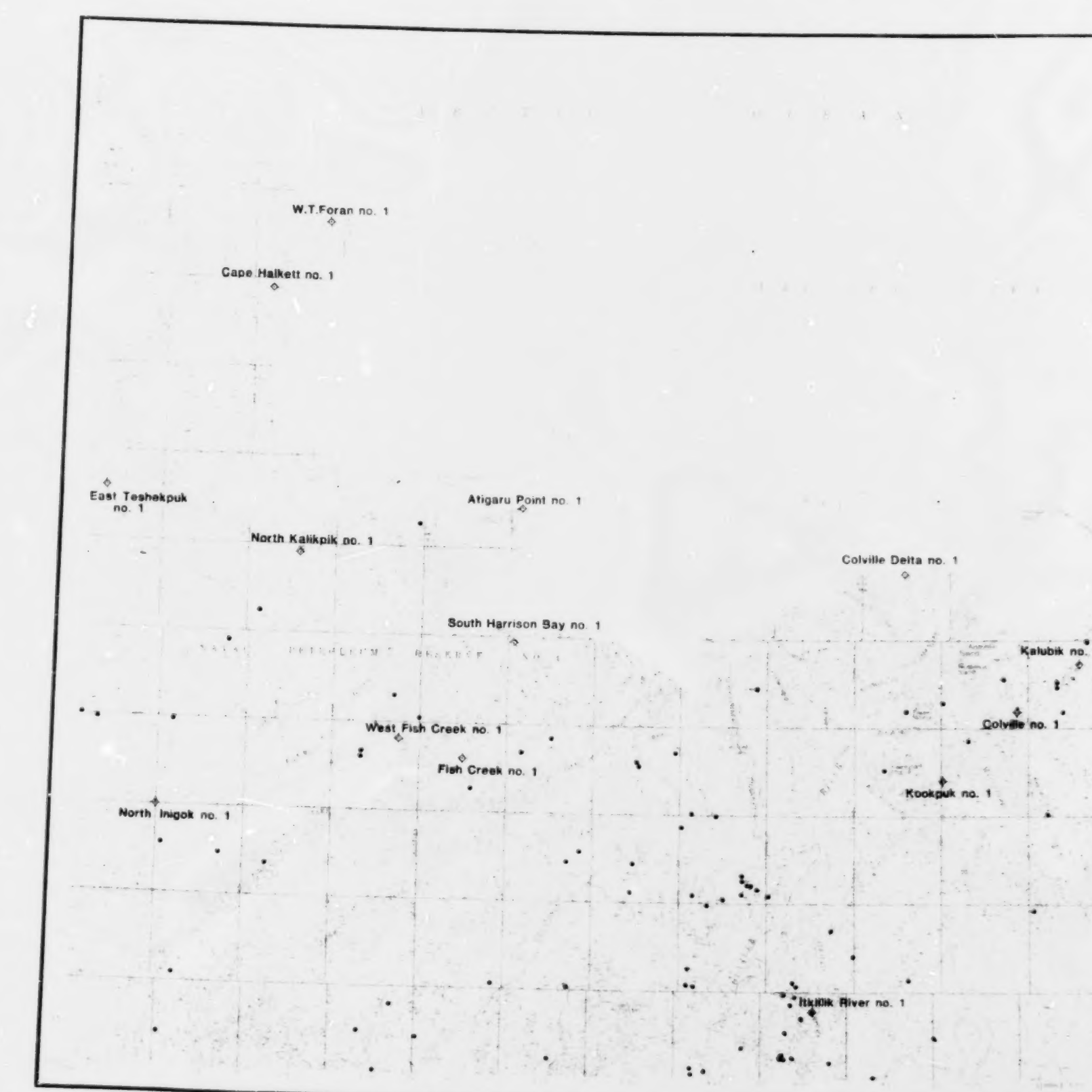
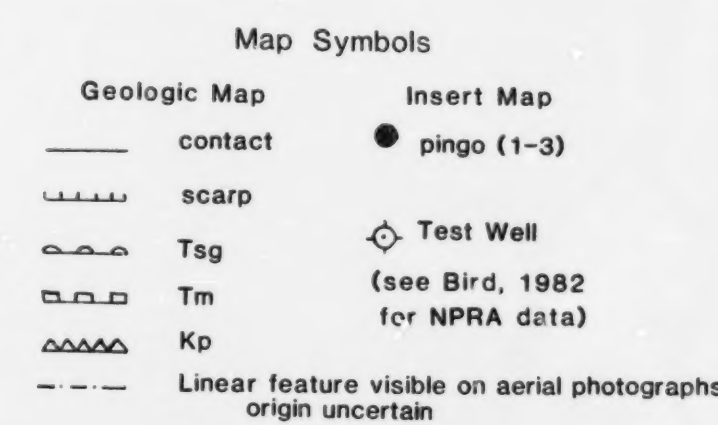
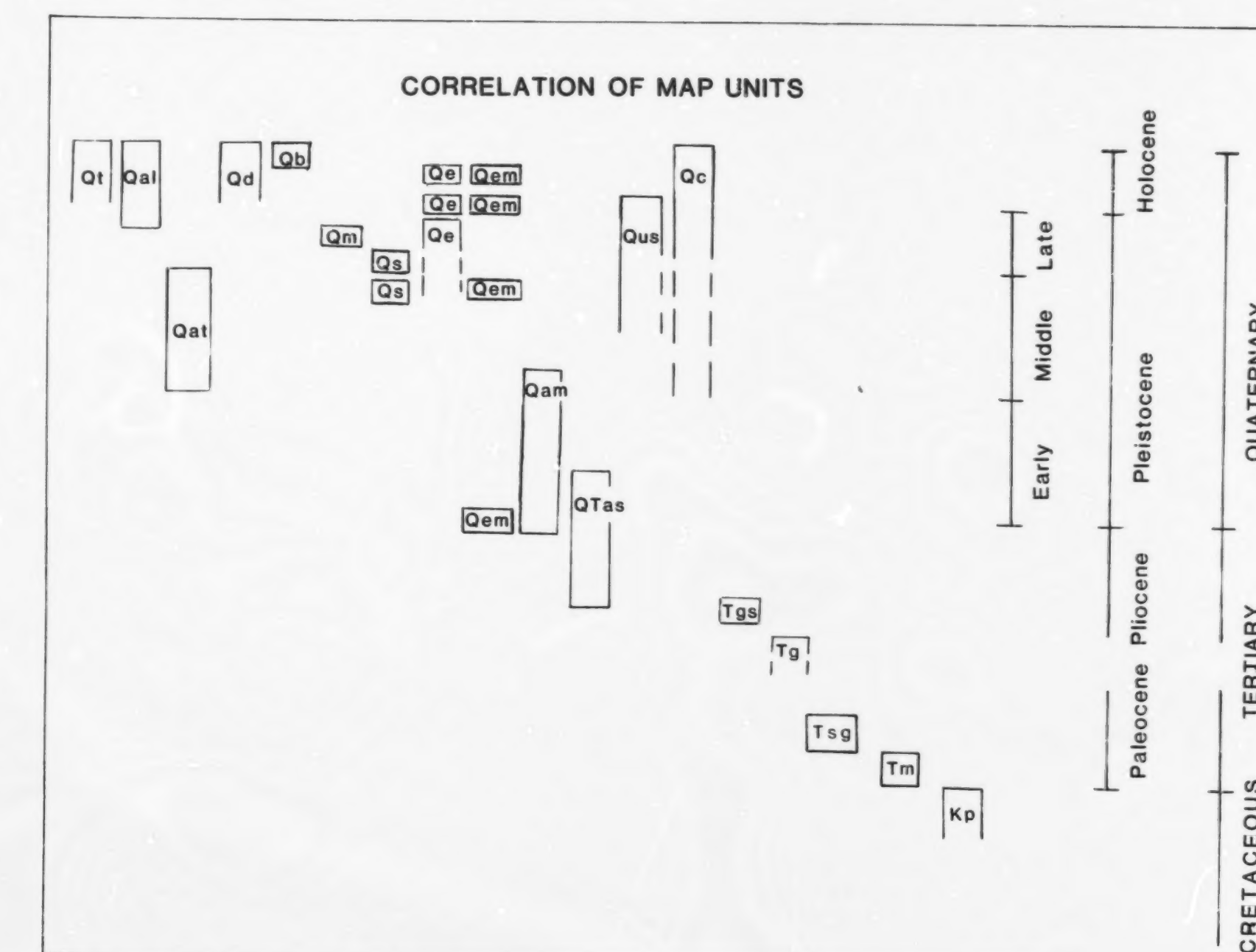
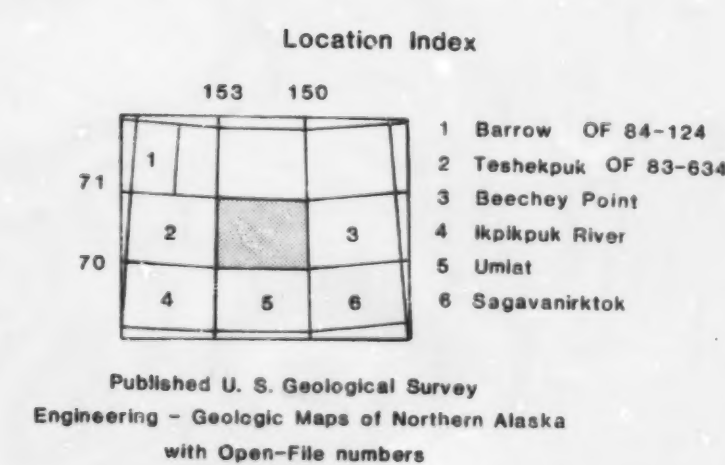
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Base from USGS 1:250,000 Harrison Bay 1955, 100 ft

Geology mapped 1977 - 1982



DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Q1	Thaw-lake deposits
Qal	Alluvium
Qat	Aluvial terrace
Qd	Deltaic deposits
Qb	Beach deposits
Qm	Marine silt and clay
Qs	Marine sand over silt and clay
Qe	Eolian sand
Qem	Thin eolian sand over marine silt and clay
Qam	Alluvial sand over marine silt and clay
QTas	Alluvial and eolian sand and marine sand and silt
Qc	Colluvial deposits
Qus	Upland sand and silt
Tgs	Gravelly sand
Tp	Gravel
Tsg	Sand, gravelly sand, conglomerate, and pebbly mud
Tm	Marine siltstone, shale, and sandstone
Kp	Nonmarine sandstone, siltstone, and shale

Description of materials	Distribution and thickness
Q1 Lithology dependent upon the materials in which the lake develops. In the area underlain by marine silt and clay (Qm) west of Harrison Bay the lake deposits consist of silt and clay. Lake deposits developed in units Q1, Q2, Q3, Q4, Q5, and Q6 are fine to medium sand and silt sand, thin to medium sand (Q1) consist of fine sand and lake deposits formed in the upper silt unit (Q2) are composed of silt to very fine sand. (Q3) are mud flat formed by coastal erosion breaching thaw-lake basins. All of the deposits contain disseminated detrital organic matter and clasts of peat of various sizes. Sorted, discrete, cobble to boulder-sized erratics and lenses of granules to small pebbles occur where the lake deposits are developed in Q1 or Q2. Unit includes the deposits of minor streams that cross or connect lake basins.	Q1 Occurs throughout the quadrangle but not differentiated in alluvium or deltaic deposits. Generally less than 3 m thick.
Qal Stratified deposits of fine to medium sand, silt, sand, and gravelly sand. Coarse sand and minor gravel occur locally along streams west of the Colville River, except in the Q4 map unit. Cobble and boulder occur in the bed of the river, the Yukon River, but do not indicate a gravel deposit because they are concentrated from lag that occurs in the basal bed of the Q4 map unit. Gravel and gravelly sand common along the Colville River and streams to the west. Contains detrital wood and peat. Includes deposits of flood-plain lakes and thaw lakes. Organic-rich silt common as thin overbank deposits and as thicker laminae deposits that fill abandoned channels. Small silt dunes are common on modern point bars.	Qal Occurs along all the major streams in the quadrangle, but is most extensive along the Colville and Yukon Rivers, which head in the Brooks Range. Includes flood-plain and alluvial terrace deposits as much as 8 m above modern streams. Probably not more than 3 m thick along modern channels, except along the Colville and Yukon Rivers where the deposits may be as thick as 20 m.
Qat Fluvial deposits of interbedded silt, sand, gravelly sand, and minor pebbles to cobbles. Clast rock types include chert, sandstone, and chert pebbles, conglomerate. Detrital wood and clasts of peat locally common. Occurs in this eolian sand and peat. Penetrated and deformed by sand wedges.	Qat Occurs on both sides of the Colville and Yukon Rivers, and along the Fish Creek in the northeastern part of the quadrangle. The thickness generally that occur from 5 to 10 m above modern flood plains. Drainage generally good.
Qd Silt and mud grading to silt at the coast. Contains some very fine-grained organic matter. Cobble gravel occurs locally along the Fish Creek where the channel is eroding the gravelly materials of map unit Qat.	Qd Occurs at the mouth of the Colville and Yukon Rivers and at the mouth of Fish Creek in the northeastern part of the quadrangle. The thickness is underlain by silt and peat from 0.5 to 2 m thick.
Qb Marine deposits of gravelly sand and sand, locally with considerable amounts of detrital organic material including peat and wood. Gravel composed of chert, granite, quartzite, dolomite, diabase, and rock types and is derived from erosion of older deposits.	Qb Present locally along the northern part of Kupuk River and the Beaufort Sea coast, and an offshore island. Deposits are thin and narrow, generally from 1 to 3 m thick and from 10 to 20 m wide.
Qm Clayey silt, silt clay, and minor sandy silt. Includes thin, superposed marine deposits of two or more marine transgressions. The uppermost of these contains scattered interbedded pebbles, cobbles, and boulders of rock types, plus quartzite, dolomite, and other rock types not found in streams draining the north flank of the Brooks Range. Also present are the remains of marine mammals, mollusks, foraminifers, and ostracodes. The upper two of these deposits have been extensively reworked by thaw-lake activity and are overlain by 1 to 2 m of peat.	Qm Occurs in the northeastern part of the quadrangle east of Harrison Bay. Thickness not determined, but extends at least to the base of coastal bluffs that are as much as 6 m in height.
Qs Predominantly silt with scattered granules and pebbles, but along the north edge of the silt includes peat of pebbly sand that may be barrier island deposits. These are best exposed along the north side of Kupuk River. The pebbles consist of chert of probable Brooks Range derivation and of the exotic rock types described for Q1. The pebbly deposits contain abundant marine mollusks, foraminifers, and ostracodes. Sparse sea mammal remains, and locally common driftwood. Elsewhere, the sand contains sparse remains of marine mollusks, ostracodes, and foraminifers. Underlying the marine sand at altitudes that range from sea level to about 2 m is marine silt and clay that, south of Kupuk River, locally contains pebbles, cobbles, and boulder-sized fragments of the rock type described for Q1. The silt and clay contain marine mollusks and foraminifers, but no mollusks have been collected within this quadrangle. Overlying the marine sand are thin laminae of eolian deposits and peat, and wedges of fine to very fine eolian sand that penetrate and deform the marine sand and the upper part of the marine silt and clay.	Qs Occurs adjacent to and west of Kupuk River in the west-central part of the quadrangle. The sand ranges from 1 to 4 m thick, and the underlying marine silt and clay is of undetermined thickness. The overlying deposits are generally 1 to 2 m thick.
Qe Fine to very fine sand containing abundant quartz with minor dark minerals. Well sorted. Stratified, with large-scale cross bedding in places. Contains peat beds and wood in upper few m. Marine silt and clay and fluvial silt and pebbly sand exposed beneath the eolian sand on outcrops on the north side of Fish Creek.	Qe Occurs most of the southwestern part of the quadrangle. Thickness ranges from a few m to more than 20 m. This unit forms the eastern edge of a large sand sea (Carter, 1981).
Qem Fine sand containing abundant quartz with minor dark minerals. Well sorted, poorly stratified. Contains peat beds and within druse in gravelly portion in upper part. In lower part includes sand wedges which also penetrate and deform underlying materials. Beneath the eolian sand at altitudes that range from sea level to about 5 m is marine silt and clay similar to that described for the lower part of Q1 except that erratics have been observed only in the northern and northeastern part of the map unit, and marine mollusks have been collected from exposures along the Kaligak River in the south-central part of the map unit.	Qem Occurs west of Harrison Bay and south of Kupuk River in the west-central part of the quadrangle. The eolian sand is from 2 to 6 m thick and the marine silt and clay is of undetermined thickness.
Qam Predominantly fluvial silt with scattered granules and pebbles, but includes minor sandy pebbly gravel. Pebbles composed primarily of chert and quartz. Overlies marine silt and clay which is exposed at altitudes that range from 8 to 20 m. Overlying the fluvial sand is thin eolian sand and peat and wedges of fine to very fine eolian sand that penetrate and deform the alluvial sand.	Qam Occurs on both sides of July Creek and east of the Kachemak River in the southern part of the quadrangle. Fluvial sand is 2 to 6 m thick, marine silt and clay of undetermined thickness.
QTas Highly variable composition, but generally consists of stratified deposits of marine silt with gravelly sand, silt, and minor clay, and thin to medium sand, gravelly sand, and minor organic-rich silt, which in turn locally is overlain by eolian sand. In places, marine deposits do not occur, and only fluvial and eolian deposits are present. The base of the marine deposits is exposed only in bluffs along the right bank of the Colville River, where it is marked by a sparse lag of pebbles, cobbles, and boulders. Rock types in the lag include those characteristic of map units Q1 and Q2. The marine deposits commonly are fossiliferous, containing mollusks, foraminifers, ostracodes, and rare marine mammal remains. The deposits of two marine transgressions occur and locally may be superposed. Fluvial deposits locally contain buried peat beds, and logs of spruce, larch, and poplar. The lower part of the eolian sand contains ventifacted pebbles of chert and quartz derived from the fluvial deposits. Wedges of pebble-free eolian sand penetrate and deform the underlying deposits. Peat and/or peaty silt sand occurs at the top of the unit.	QTas Occurs on both sides of the Colville River in the southeastern part of the quadrangle. Thickness of marine deposits 1 to 8 m; fluvial deposits 10 to 20 m; eolian deposits 2 to 5 m; peat and peaty sand 1 to 2 m. Aggregate thickness 12 to 20 m.
Qc Silt and very fine sand with dispersed pebbles and cobbles. Contains disseminated, fine-grained organic matter and, in places, clasts of peat of various sizes, and pieces of detrital wood. Bones of extinct Pleistocene mammals locally present.	Qc Occurs in the southeast corner of the map and along the east side of the Colville River - Yukon River valley. Thickness from 1 to 10 m.
Qus Predominantly wind blown, very fine sand and silt. Includes some clay and layers and lenses of chert granules and pebbles. Stratification indistinct. Unusually sand to sandy gravel. Clasts predominantly pebble-sized, well rounded, and composed of chert and quartz. Very poorly exposed.	Qus Occurs only in the southwest corner of the quadrangle. Ranges from a few m to as much as 10 m.
Tgs Gravelly sand to sandy gravel. Clasts predominantly pebble-sized, well rounded, and composed of chert and quartz. Very poorly exposed.	Tgs Occurs on the west side of the Colville River - Yukon River valley in the southwestern part of the quadrangle, where it underlies Q1as. Thickness about 1 to 3 m.
Tp Pebble, cobble, and boulder gravel. Clasts predominantly of hard, resistant rock types common in nearby parts of the Brooks Range, including chert, quartz, sandstone, and chert pebbles, conglomerate. Gravel to 1.5 m in diameter locally contains largest erratics observed (5 m in diameter. Poorly exposed parts of deposit may have silt matrix and may be till.	Tp Occurs in the southeast corner of the quadrangle. Up to 20 m thick. Probably underlies most of map unit Q1.
Tsg Homomeric, moderately to poorly consolidated deposits of variable composition, ranging from conglomerate to pebbly sand to pebbly mud. Includes silt, sand, gravel, gravelly sand, sand, and pebbly mud at other localities. Contains clasts up to 1.5 m in diameter composed of metamorphic, intrusive, and volcanic rock types which do not occur in nearby parts of the Brooks Range and which are distinct from the rock types found in younger glaciolacustrine deposits. Locally contain light-colored logs of large coniferous trees. Contains disseminated sulfur in places. Some granitic clasts weathered to gray.	Tsg Exposed in river cut banks at widely separated localities in the southeastern part of the quadrangle on the Yukon River west of Kupuk, on the west side of the Colville River opposite the mouth of the Yukon River, at three places on the west side of the Kachemak River, and at one locality on the west side of the Yukon River. Exposed thickness (unconsolidated) ranges from 2 to 8 m; total thickness considerably greater but unknown. Overlain by 1 to 10 m of younger deposits.
Tm Marine siltstone, shale, and sandstone. This to medium bedded, poorly indurated. Contains fossil mollusks, ostracodes, and foraminifers.	Tm Occurs near Ocean Point along the north side of the Colville River. Exposed thickness about 20 m.
Kp Homomeric sandstone, siltstone, and shale with minor sandy beds and thin lignite layers. Thinly to thickly bedded, commonly to poorly indurated. Fine-grained beds are commonly laminar. Part of the type section for the upper part of the Saginaw-Tongue of the Prince Creek Formation (Galloway and Whittington, 1966).	Kp Occurs near the southern border of the map on the west side of the Colville River. The measured thickness (unconsolidated) of the upper part of the Kachemak-Tongue is 253 m (Galloway and Whittington, 1966).

Topography and drainage	Permafrost
Q1 Forms flat to moderately dissected areas within isolated, interlocking, or overlapping basins. Maximum surface relief within basins ranges from about 2 m to 10 m and is determined by the degree of dissection and presence of ridges. Fluvial occur primarily in lake deposits developed in eolian sand (Galloway and Carter, 1978; Carter and Galloway, 1978) and attain a maximum height of about 10 m. Maximum relief between basin floors and surrounding areas ranges from about 5 m to 15 m. Drainage is poor except in those basins in the eolian sand unit that have been breached and deeply dissected.	Q1 Permanently frozen immediately below a thin active layer about 0.5 m thick. Amount of active ice is largely dependent upon the age of the deposits, silt, silt, and amount of detrital organic matter. Deposits in the central part of recently drained basins may have relatively low ice contents. However, wedge ice in the subject strata may have survived the lake episode if the lake was shallower than 2 m.
Qal Forms channels and bars of the modern rivers and terraces of older river courses. Meander scrolls are well preserved on the lower terraces. Terrace drainage generally poor. Subject to flooding to 5 or 6 m above low water stage streams.	Qal Permafrost underlies the entire unit except for a 2 to 6 m thick unfrozen layer beneath some of the larger channels and lakes, and a thicker (perhaps periglacial) unfrozen zone beneath the Colville River. Elsewhere, active layer about 0.5 m thick. Ice wedges are well developed in the terrace materials, and the silt deposits that form the filling material of abandoned channels contain abundant interstitial ice.
Qat Forms residual surfaces between the lake basins. Surfaces are fluvial terrace remnants that occur from 5 to 10 m above modern flood plains. Drainage generally good.	Qat Permafrost present beneath an active layer that is generally less than 0.5 m thick. Ice wedges occur in the upper few m.
Qd Forms channels, banks, islands, meanders, and mudflats of the modern delta. Very poorly drained. Lakes and ponds common on islands. Low dunes common on and adjacent to sandbars.	Qd Islands are underlain by permafrost and contain active ice wedges. Active layer generally less than 0.5 m thick beneath dunes covered areas; somewhat thicker beneath bare ground. Open talus cover beneath the deepest channels and sandbars.
Qb Forms low ridges along and slightly inland from the modern shorelines. Drainage good on ridges but where more than one ridge is present the inter-ridge areas are poorly drained.	Qb The active layer on presently forming beaches and spits may be as much as 2 m thick. Inactive beach ridges may have actively growing ice wedges. Probably contains less total ice than sandy and silt deposits of other map units.
Qm Forms poorly to moderately well drained surfaces isolated by thaw-lake basins.	Qm Permanently frozen beneath an active layer that is generally less than 0.5 m thick. Active ice wedges well developed and fossil ice wedges locally occur at depths of a few m. Interstitial ice content in excess of natural voids down to 6 or 8 m below surface and may produce more settlement upon thawing than the 3.3 m noted in marine sand near Barrow (Hosby and Heston, 1966).
Qs Forms residual surfaces between the lake basins. Drainage generally good. Not subject to movement flooding.	Qs Permafrost present beneath an active layer that is generally less than 0.5 m thick. Ice wedges well developed and interstitial ice content high. Similar deposits near Barrow are superimposed with ice down to about 4 or 6 m (Galloway and others, 1975), with ice content of 75% by volume at a depth of 1 m, exclusive of wedge ice.
Qe Forms generally well drained linear dune ridges as much as 20 m high upon which are superimposed periglacial dunes that are generally less than 1 m high. Contains poorly drained depressions that are not part of an integrated drainage system.	Qe Permafrost underlies entire unit. Active layer less than 1.5 m thick on well drained ridges and summits and less than 0.5 m thick in poorly drained depressions. Ice wedges occur in the upper few m but the maximum of the deposits is generally free of excess ice in excess of natural voids. However, the presence of deep lakes (Galloway and others, 1978) may indicate that the eolian sand overlies sediments that contain large amounts of massive ice.
Qem Forms residual surfaces between the lake basins. Common periglacial dunes which are less than 1 m high. Drainage generally good. Not subject to movement flooding.	Qem Permafrost present beneath an active layer that is generally less than 0.5 m thick. Ice wedges occur in the upper few m, and interstitial ice in excess of natural voids probably is present in the marine silt and clay.
Qam Forms residual surfaces between the lake basins. Drainage generally good. Not subject to movement flooding.	Qam Permafrost present beneath an active layer that is generally less than 0.5 m thick. Ice wedges occur in the upper few m, and interstitial ice in excess of natural voids probably is present in the marine silt and clay.
QTas Forms flat to gently rolling terrain broken by thaw-lake basins and ridges. Drainage good on slopes, fair to poor on flatter surfaces.	QTas Permanently frozen beneath an active layer that is generally less than 0.5 m thick. Ice wedges occur in the upper few m. Silt, organic-rich silt, and clay may have interstitial ice in excess of natural voids.
Qc Forms valley and gully slopes and bottoms. Drainage good on upper slopes, poor on lower slopes and in valley and gully bottoms.	Qc Highly frost susceptible.
Qus Forms flat to gently rolling terrain broken by dunes, thaw-lake basins, major stream valleys, and ridges. Drainage good on slopes, fair to poor on flatter surfaces.	Qus Active layer generally less than 0.5 m thick. Ice wedges well developed and sediment may contain a high volume of interstitial ice.
Tgs Forms an isolated bench on the valley side. Well drained.	Tgs Permanently frozen beneath an active layer that is probably less than 1 m thick. Ice content unknown but probably not in excess of natural voids.
Tp Forms bluffs on the upper slopes of valleys. Well drained.	Tp Active unit is permanently frozen. Thickness of active layer is unknown but may be as much as 2 m in ungravelled, south-facing slopes. Ice content not known but probably not in excess of natural voids.
Tsg Forms the lower parts of river cut banks. Drainage generally good.	Tsg Permanently frozen. Generally low ice content but fine-grained units may contain ice in excess of natural voids.
Tm Forms the lower 20 m of 35 m-high bluffs. Well drained.	Tm Permanently frozen but ice content insignificant.
Kp Forms the lower 20 m of 35 m-high bluffs. Well drained.	Kp Permanently frozen but ice content insignificant.

DESCRIPTION OF MAP UNITS

Permafrost	Susceptibility to frost action
Q1 Permanently frozen immediately below a thin active layer about 0.5 m thick. Amount of active ice is largely dependent upon the age of the deposits, silt, silt, and amount of detrital organic matter. Deposits in the central part of recently drained basins may have relatively low ice contents. However, wedge ice in the subject strata may have survived the lake episode if the lake was shallower than 2 m.	Q1 Highly frost susceptible where developed in marine silt and clay. Susceptibility in remainder of area varies within individual lake deposits depending upon silt content and amount of detrital organic matter. Deposits in the central part of lake basins generally very susceptible due to concentration of silt and organic matter.
Qal Permafrost underlies the entire unit except for a 2 to 6 m thick unfrozen layer beneath some of the larger channels and lakes, and a thicker (perhaps periglacial) unfrozen zone beneath the Colville River. Elsewhere, active layer about 0.5 m thick. Ice wedges are well developed in the terrace materials, and the silt deposits that form the filling material of abandoned channels contain abundant interstitial ice.	Qal Organic-rich silt materials that fill abandoned channels and form overbank deposits are highly frost susceptible. Point bar and channel deposits with less than 6 percent silt are generally not frost susceptible.
Qat Permafrost present beneath an active layer that is generally less than 0.5 m thick. Ice wedges occur in the upper few m.	Qat Silt sand marginally frost susceptible depending on silt content.
Qd Islands are underlain by permafrost and contain active ice wedges. Active layer generally less than 0.5 m thick beneath dunes covered areas; somewhat thicker beneath bare ground. Open talus cover beneath the deepest channels and sandbars.	Qd Highly frost susceptible.
Qb The active layer on presently forming beaches and spits may be as much as 2 m thick. Inactive beach ridges may have actively growing ice wedges. Probably contains less total ice than sandy and silt deposits of other map units.	Qb Granular materials not susceptible to frost action.
Qm Permanently frozen beneath an active layer that is generally less than 0.5 m thick. Active ice wedges well developed and fossil ice wedges locally occur at depths of a few m. Interstitial ice content in excess of natural voids down to 6 or 8 m below surface and may produce more settlement upon thawing than the 3.3 m noted in marine sand near Barrow (Hosby and Heston, 1966).	Qm Highly frost susceptible.
Qs Permafrost present beneath an active layer that is generally less than 0.5 m thick. Ice wedges well developed and interstitial ice content high. Similar deposits near Barrow are superimposed with ice down to about 4 or 6 m (Galloway and others, 1975), with ice content of 75% by volume at a depth of 1 m, exclusive of wedge ice.	Qs Sand marginally frost susceptible, depending on silt content. Marine and lacustrine silt and clay highly frost susceptible.
Qe Permafrost underlies entire unit. Active layer less than 1.5 m thick on well drained ridges and summits and less than 0.5 m thick in poorly drained depressions. Ice wedges occur in the upper few m but the maximum of the deposits is generally free of excess ice in excess of natural voids. However, the presence of deep lakes (Galloway and others, 1978) may indicate that the eolian sand overlies sediments that contain large amounts of massive ice.	Qe Generally not frost susceptible, except where silt content exceeds 6 percent.
Qem Permafrost present beneath an active layer that is generally less than 0.5 m thick. Ice wedges occur in the upper few m, and interstitial ice in excess of natural voids probably is present in the marine silt and clay.	Qem Eolian sand generally not frost susceptible, except where silt content exceeds 6 percent. Silt and clay highly frost susceptible.
Qam Permafrost present beneath an active layer that is generally less than 0.5 m thick. Ice wedges occur in the upper few m, and interstitial ice in excess of natural voids probably is present in the marine silt and clay.	Qam Silt sand generally frost susceptible. Silt and clay highly frost susceptible.
QTas Permanently frozen beneath an active layer that is generally less than 0.5 m thick. Ice wedges occur in the upper few m. Silt, organic-rich silt, and clay may have interstitial ice in excess of natural voids.	QTas Silt sand generally frost susceptible. Silt and clay highly frost susceptible.
Qc Highly frost susceptible.	Qc Generally unsuitable as a source for materials because of organic content. Not suitable for foundations on lower slopes and valley bottoms because of excessive differential settlement on thaw of ice-rich permafrost.
Qus Active layer generally less than 0.5 m thick. Ice wedges well developed and sediment may contain a high volume of interstitial ice.	Qus Not suitable for borrow except as binder material. Not suitable for foundations because of excessive differential settlement on thaw of ice-rich permafrost.
Tgs Permanently frozen beneath an active layer that is probably less than 1 m thick. Ice content unknown but probably not in excess of natural voids.	Tgs Probably not frost susceptible.
Tp Active unit is permanently frozen. Thickness of active layer is unknown but may be as much as 2 m in ungravelled, south-facing slopes. Ice content not known but probably not in excess of natural voids.	Tp Susceptible to frost action where matrix is silt.
Tsg Permanently frozen. Generally low ice content but fine-grained units may contain ice in excess of natural voids.	Tsg Fine-grained beds susceptible to frost action.
Tm Permanently frozen but ice content insignificant.	Tm Fine-grained sand and/or thin bedded units susceptible to frost action.
Kp Permanently frozen but ice content insignificant.	Kp Thin bedded and/or fine-grained units susceptible to frost action.

Buildability for construction	Special problems
Q1 Generally unsuitable as a source of materials due to silt, organic and ice content and the seasonal flooding of the lake basins by snow melt. The older deposits are less suitable as construction sites due to increasing amount of excess ice with age.	Q1 Differential settlement may occur upon thaw of permafrost. Very poor drainage except where deeply bedded. Fluvial common where thaw-lake deposits developed in eolian sand.
Qal Provides good foundations in channel and bar areas where material consists of medium to coarse sand, gravelly sand, and gravel; and moderately good to poor foundations on terraces and the older parts of flood-plain. Organic-rich lacustrine silt that fills abandoned channels is not suitable for foundations. Deposits with low silt content may be suitable for fill.	Qal Subject to bank erosion, scour, channel shifting, and seasonal flooding. Wind erosion and dune building common on point bars and would occur on other parts of the flood plain and on terraces if surface vegetation is disturbed. Reclamation of stream-bed materials may pose environmental problems.
Qat Not suitable for foundations because of excessive differential settlement on thaw of ice-rich permafrost. Sand, and locally gravel, may be suitable for fill, base course, or surfacing.	Qat Easily eroded by running water if flow is concentrated by construction activities or if surface vegetation is removed. Susceptible to wind erosion if surface vegetation is removed. Sand-wedge materials may be liquefiable when thawed and saturated.
Qd Incompatible with proper silt content may be suitable for borrow, but excavation may pose environmental problems and would be subject to flooding. Not suitable for foundations due to frost susceptibility, poor drainage, and frequent channel shifts.	Qd Subject to seasonal flooding, formation of river-ice dams, bank erosion, scour, and channel shifting.
Qb Poor for materials due to silt and organic content and unsuitable size grading. Otherwise, generally good except may require addition of binder for surfacing or base course. Materials of limited volume.	Qb Subject to ice shove along shore and subject to storm surge flooding below 2 m in altitude. Excavation of actively forming beaches need impact evaluation to determine effect of borrowing activities on coastal erosion and deposition.
Qm Not suitable for foundations because of excessive differential settlement on thaw of ice-rich permafrost. Construction materials not readily available.	Qm Easily eroded. Silt has high liquefaction potential when thawed.
Qs Not suitable for foundations because of excessive differential settlement on thaw of ice-rich permafrost. Sand may be suitable for fill, base course, or surfacing if silt content is appropriate and if stabilized to prevent deflation.	Qs Easily eroded by running water if surface vegetation is removed or if flow is concentrated by construction activities. Material forming the sand wedges may be liquefiable when thawed and saturated.
Qe Adequate for natural foundations but requires stabilization for use as a surfacing material or fill. Relatively easy to excavate with a ripper on well drained dune ridges.	Qe Extremely susceptible to wind erosion when protective vegetation is removed. Very sensitive to surface disturbances. Active dunes present in places. Locally, sand may be liquefiable when thawed and saturated.
Qem Not suitable for foundations because of excessive differential settlement on thaw of ice-rich permafrost. Sand may be suitable for fill, base course, or surfacing if silt content is appropriate and if stabilized to prevent deflation.	Qem Extremely susceptible to wind erosion if surface vegetation is removed. Easily eroded by running water if flow is concentrated by construction activities or if surface vegetation is removed. Material forming the sand wedges may be liquefiable when thawed and saturated.
Qam Not suitable for foundations because of excessive differential settlement on thaw of ice-rich permafrost. Sand may be suitable for fill, base course, or surfacing if silt content is appropriate and if stabilized to prevent deflation.	Qam Easily eroded by running water if flow is concentrated by construction activities or if surface vegetation is removed. Sand-wedge filling subject to liquefaction if thawed and saturated. Susceptible to wind erosion if surface vegetation is removed.
QTas Not suitable for foundations because of excessive differential settlement on thaw of ice-rich permafrost. Sand may be suitable for fill, base course, or surfacing if silt content is appropriate and if stabilized to prevent deflation.	QTas Easily eroded by running water if flow is concentrated by construction activities or if surface vegetation is removed. Sand-wedge filling subject to liquefaction if thawed and saturated. Susceptible to wind erosion if surface vegetation is removed.
Qc Generally unsuitable as a source for materials because of organic content. Not suitable for foundations on lower slopes and valley bottoms because of excessive differential settlement on thaw of ice-rich permafrost.	Qc Easily gulled by running water. Disruption of surface vegetation on lower slopes and valley bottoms may cause melting of ground ice and lead to subsidence.
Qus Not suitable for borrow except as binder material. Not suitable for foundations because of excessive differential settlement on thaw of ice-rich permafrost.	Qus Easily gulled by running water when water is channelled by construction activities or when surface vegetation is removed. Disruption of surface vegetation may cause melting of ice wedges and lead to subsidence. Locally deposits may be liquefiable when thawed and saturated.
Tgs Not suitable for borrow due to thickness of overburden (Q1as).	
Tp Suitable for fill, base course, and surface course (with proper grading), but unsatisfactory for aggregate because of chert content. Provides good foundations near bluff tops where silt cover is not excessive.	
Tsg Not suitable for borrow due to thickness of overburden and extensive weathering of some clasts.	
Tm Not suitable for borrow due to thickness of overburden.	Tm Subject to debris flows and rock falls.
Kp Not suitable for borrow due to thickness of overburden.	Kp Subject to debris flows and rock falls.

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by
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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.